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FLYING HOURS AND AIRCREW PERFORMANCE

Colin P. Hammon
Stanley A. Horowitz, Project Leader

March 1990

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This work addresses the development of quantitative relationships between how much aircrews have flown and how well they perform important aspects of their missions. It is determined that additional flying enhances proficiency in two ways: through the short-run honing of skills and through the long-run development of mastery. Estimates of the strength of the links between flying experience and three measures of performance are developed. The measures are: bombing accuracy, the quality of landings aboard aircraft carriers, and kills in air combat maneuvering exercises. In general, it is found that while both short-run and long-run experience are important, career experience has a stronger relationship than recent experience to performance.

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Stanley A. Horowitz, *Project Leader*

March 1990

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PREFACE

This document was prepared by the Institute for Defense Analyses (IDA) for the Office of the Assistant Secretary of Defense (Force Management and Personnel), under contract MDA 903 89 C 0003, Task Order T-L7-516, issued 17 June 1987, and amendments. The objective of the task was to help develop quantitative relationships between aviation units' ability to perform their missions and the levels of training resources available to them.

The authors thank George Tilson for his encouragement, advice, and support. Without Robert Croach and Robert Nemetz the work would never have been started. David Armor provided important insight. Matthew Goldberg made valuable comments on the manuscript. Linda Garlet and Andrea Zimmet prepared the document for publication.

One of the authors of this document, Colin P. Hammon, is an IDA consultant.

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I. INTRODUCTION

This paper develops quantitative relationships between how much aircrews have flown and how well they perform important aspects of their missions. In part, the research described here is in response to concerns voiced by the General Accounting Office and skepticism displayed by Congress about the impact of cuts to the flying hour programs of the services [1].

An earlier paper described the small body of existing literature that has developed such relationships [2].[1] It reached the following overall conclusions:

- Quantitative relationships that support the proposition that more flying results in measurably better performance have been developed for both the Air Force and the Navy.
- Additional flying appears to improve aircrew performance in two ways. In the short run it hones skills and prevents their deterioration. In the long run it permits the attainment of a higher level of mastery that is reflected in better performance. None of the existing analyses that were reviewed fully captures both of these effects.
- Data exist to develop additional links between flying hour activity and measures of operational performance for a wide range of aircraft. Additional research to build such links should be developed.

Our purpose here is to report the results of new statistical analyses that examine both the long-range and short-range effects of flying hours on performance, and to briefly review efforts that have been initiated by the services to link flying-hour histories to indicators of performance.

Three empirical investigations were undertaken. The first examined the quality of landings aboard aircraft carriers for F-14 and A-7 aircraft. The second focused on the accuracy with which Marine aviators dropped bombs from AV-8B, F/A-18, and F-4S

---

[1] Examples of quantitative relationships that have been developed statiscally include the findings that a 10% change in recent flying hours can be expected to change the number of unsuccessful attempts to land aboard aircraft carriers by 10% [3], and that a doubling of pilot experience is associated with 13% greater bombing accuracy [4].

aircraft. The third draws on the performance of F-14 fighters during opposed air-combat-maneuvering exercises on an instrumented range.

The nature and results of these investigations will be discussed in turn.

II. ANALYSIS OF CARRIER LANDINGS

A. DATA

Information was gathered on 4,351 carrier landings performed by 60 pilots flying F-14s and A-7s in Carrier Air Wing 7 between June 1985 and October 1987.[2] Data were obtained from squadron records on how many flying hours each of the pilots had accumulated in his career, and a running total of how much recent flying each had done was developed.[3] The measure of performance that we analyzed was based on carrier landing grades.

Every carrier landing attempt is graded by a landing signal officer (LSO). The LSOs are highly trained and the grading procedures that they follow are tightly specified. Squadrons monitor landing grades as an indicator of pilot proficiency and as a guide to where remedial attention should be placed.[4] Seven landing grades are possible:

- 0—dangerous.
- 1.0—wave off. The pilot was instructed not to try to land.[5]
- 2.0—"no grade." A landing was made, but landing technique was deemed faulty, though not dangerous.
- 2.5—bolter. The aircraft touched down, but it did not catch an arresting wire and was forced to take off again.[6]
- 3.0—fair pass. Some errors were made, but overall technique was not faulty.

---

[2] Landings performed by E-2Cs were also analyzed. No consistent relationships between landing performance and either short-term or long-term flying hours were found for this aircraft. This may be related to the presence of two pilots in the E-2C. There is reason to believe that crews are made up in a way that allows the deficiencies of one pilot to be compensated for by the strengths of the other. This would tend to mask the link between flying hours and proficiency.

[3] We had hoped to also get information on both recent and long-term experience in simulators, but it was not available.

[4] To the extent that poor landing performance is used to allocate flying time to those who need it the most, one would expect an inverse correlation between recent flying hours and landing grades. Observation of a positive correlation means that the effect of additional flying in building proficiency outweighs this selection effect.

[5] If a wave off is self-initiated, or if it is given for reasons related to air traffic control, the pass is graded as a 2.0.

[6] The LSO may assign a higher grade if he believes the bolter was not caused by pilot technique.

- 4.0—OK pass. A successful landing, no noteworthy mistakes were made. This is as good a grade as a pilot can reasonably expect.
- 5.0—rails pass. A perfect landing, like you're coming in on rails. This grade is very rarely given.

We decided not to analyze the numerical values of the landing grades. There is no reason to believe that a "no grade" is twice as good a performance as a wave off, or that a fair pass reflects 20% more proficiency than a bolter. Rather, categorical analyses were performed. Two categories were used: grades at least as good as 3.0 and grades at least as good as 4.0. The former can be viewed as distinguishing between satisfactory and unsatisfactory landings, the latter as distinguishing excellent landings.

To summarize the data, 86% of the landings were at least satisfactory, while 33% were excellent. Total pilot experience ranged from 351 hours to 4,501 hours, with an average of 1,516 hours. Flying in the previous month ranged up to 46 hours, but averaged 21 hours. 37% of the landings were made by F-14s and 63% by A-7s. Night landings accounted for 26% of the total.

B. ANALYSIS

The analysis sought to determine the probability that a landing would satisfy a chosen performance criterion (either satisfactory or excellent) as a function of the pilot's flying-hour history and other factors. Equations of the following form were developed:

$$\log\{p(s)/[1 - p(s)]\} = a_0 + a_1 \times H_c + a_2 \times H_{30} + a_3 \times N + a_4 \times F \ , \qquad (1)$$[7]

where

- $p(s)$ = the probability of success, either a landing grade of at least 3.0 or 4.0
- H_c = career flying hours
- H_{30} = flying hours in the previous month
- N = a dummy variable taking the value 1 for a night flight and zero otherwise

---

[7] The dependent variable in this equation is in the form of what is called a logit transformation. It has the characteristic that it constrains the predicted probability of success to be between zero and one. It leads to the probability of success being an S-shaped function of the independent variables. The coefficients in Equation (1) can be estimated using maximum likelihood techniques.

F = a dummy variable taking the value 1 for an F-14 flight and zero for an A-7 flight

a_0, a_1, a_2, a_3, a_4 = coefficients to be estimated.

The expectation is that a_1, which reflects the long-term impact of additional flying on performance, and a_2, which reflects the short-term impact, are positive. We expect a_3 and a_4 to be negative, since it is harder to land at night and since the F-14 is a heavier, harder-to-land plane than the A-7.

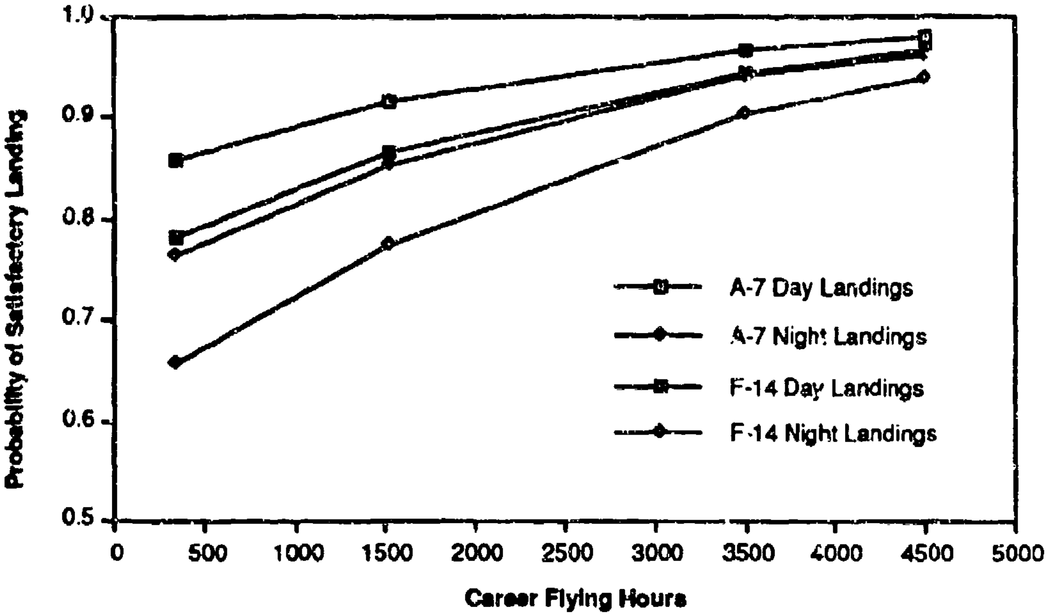
C. RESULTS

Table 1 presents the results of estimating the coefficients of equation (1). Graphical representations of the results in Table 1 are presented in Figures 1 through 4. Figures 1 and 2 show satisfactory landings and Figures 3 and 4 show excellent landings. For each success criterion, one graph depicts the effect of changing career flying hours and one depicts the effect of changing flying hours in the last month. The results confirm the hypotheses about the links between flying hours and aircrew performance.

Table 1. Determinants of the Probability of Meeting Landing Grade Criteria for A-7 and F-14 Aircraft — Logit Coefficients

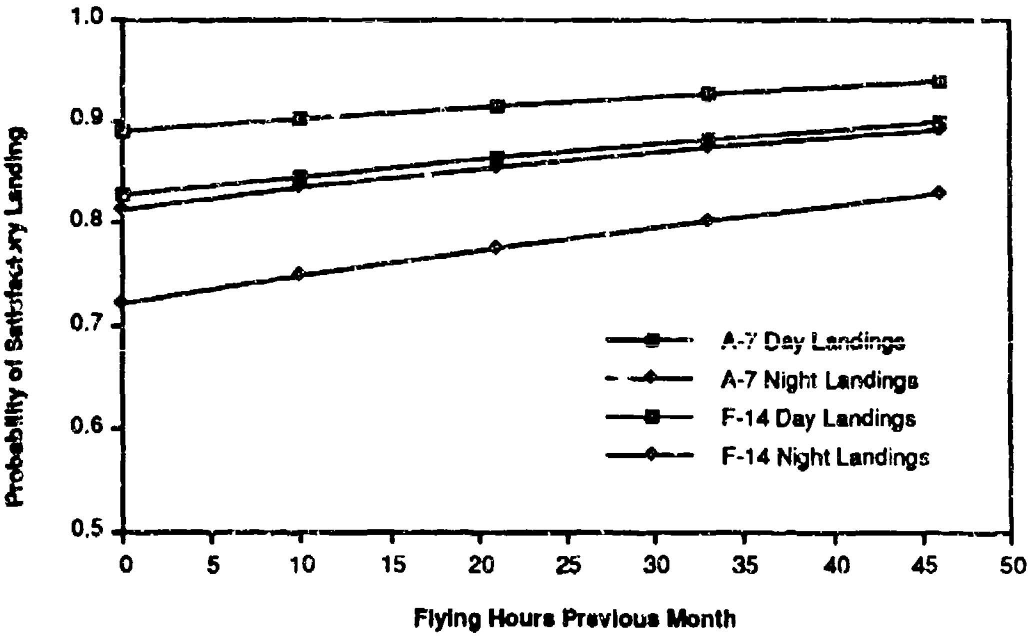
	Satisfactory Landing	Excellent Landing
Constant	1.34	-1.32
	(11.6)**	(15.2)**
Career Flying Hours	0.00050	.00024
	(9.06)**	(8.51)**
Flying Hours in the Previous Month	0.013	0.018
	(3.13)**	(5.45)**
Night Landing	-0.619	0.065
	(6.41)**	(0.87)
F-14 Flight	-0.529	-0.406
	(5.70)**	(5.65)**

Notes: Numbers in parentheses are t-values. Total observations were 4,351.
** Significant at the .99 level.



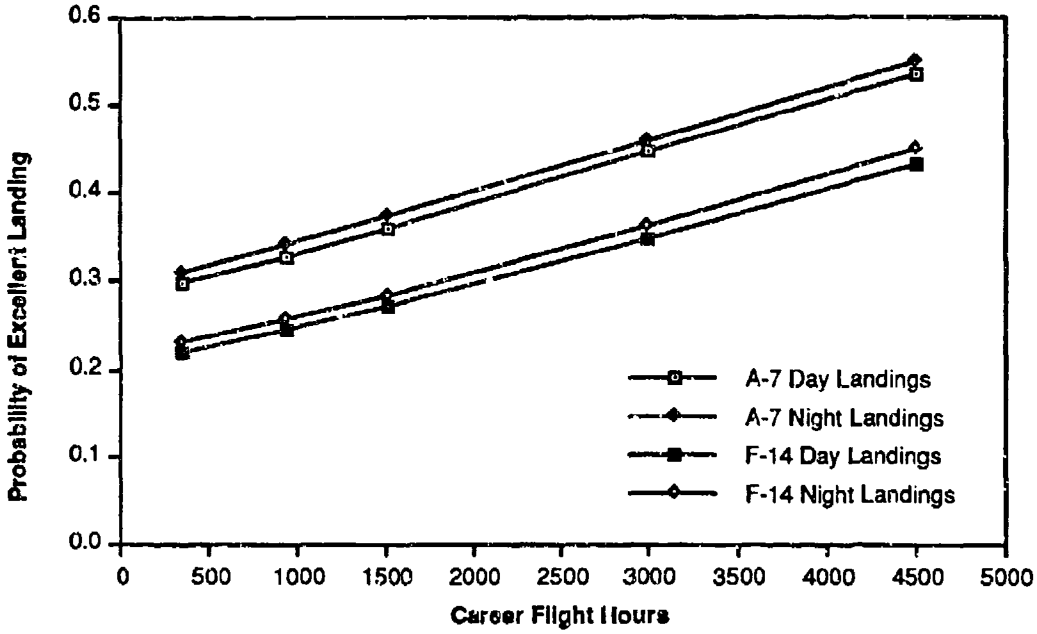
Note: Flying hours during previous month at mean.

Figure 1. Probability of Satisfactory Landing Versus Career Flying Hours



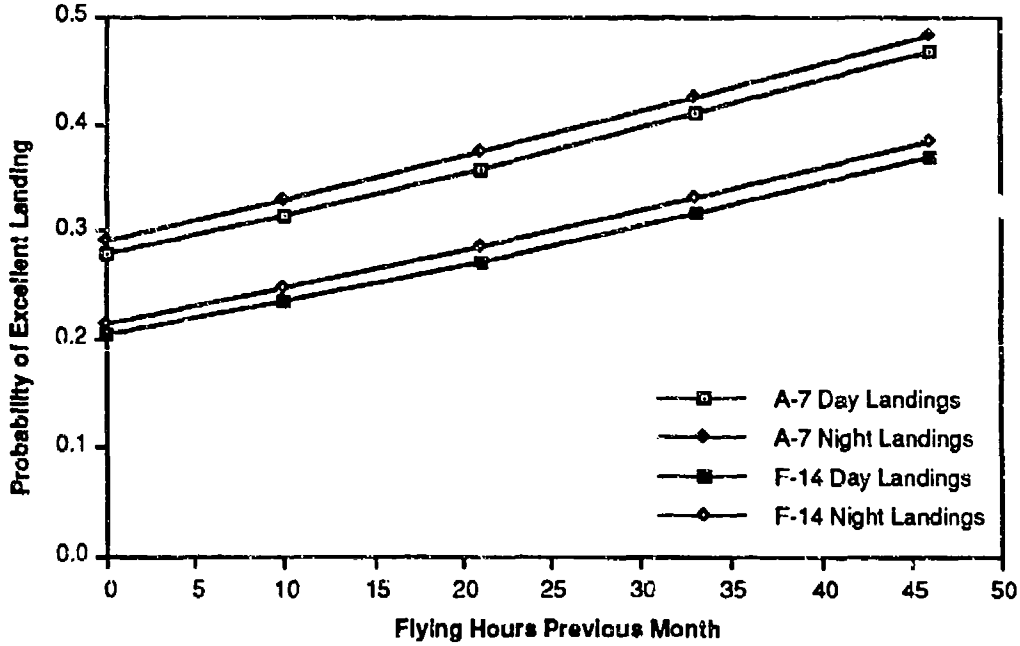
Note: Career flying hours at mean.

Figure 2. Probability of Satisfactory Landing Versus Flying Hours During Previous Month



Note: Flying hours during previous month at mean.

Figure 3. Probability of Excellent Landing Versus Career Flying Hours



Note: Career flying hours at mean.

Figure 4. Probability of Excellent Landing Versus Flying Hours During Previous Month

Both recent and long-term flying experience are associated with better performance. These relationships are highly statistically significant for both satisfactory and excellent landings. Night landings were less likely to be at least satisfactory. However, the effect of landing at night was not significantly different from zero for excellent landings.[8] F-14s received lower landing grades than A-7s.

In quantitative terms, a 10% decrease in the number of flying hours would have the short-term effect of increasing the number of unsatisfactory landings by 2.6%. The number of landings that meet the excellence criterion would decrease by 2.5%. If the decrease in flying hours continued indefinitely, it is reasonable to assume that pilots would have 10% fewer career flying hours.[9] This would yield a further increase of 6.9% in the number of unsatisfactory landings and a further decrease of 2.4% in the number of excellent landings. Thus, the total long-term effect of a 10% reduction in flying hours is estimated to be roughly 10% more unsatisfactory landings and 5% fewer excellent landings.

Most of the total effect of a reduction in flying hours is due to its implications for total career experience. Performance is less sensitive to short-term changes in flying hours than to long-term changes. This is important. It means that it would be difficult to remedy problems of inadequate performance quickly.

If performance is allowed to degrade because of inadequate flying hours limiting overall pilot experience, extremely high operating tempos would be needed to prepare for an emergency. Such operating tempos might not be sustainable. If planes are flown more intensively, more equipment will break It could well be impossible to fix the failures fast enough to keep operating tempos at the desired level. Even today, aircraft availability is sometimes a limiting factor on operating tempo in the Air Force. In addition, effective training requires use of bombing ranges and air combat maneuvering ranges (and other specialized training assets). These assets are heavily used. With the current inventory of ranges, it would not be possible to meet the requirements of a rapid improvement in

---

8 One experienced carrier pilot was not surprised by this result. He noted that there were fewer distractions at night. He acknowledged that it is more difficult to land satisfactorily at night, but felt that satisfactory landings are more likely to be excellent.

9 In fact they would probably have even fewer. One reason pilots stay in the services is to fly, and they feel less safe flying when they fly less. A decrease in flying hours would probably reduce retention and thus reduce the average number of career flying hours of the remaining pilots.

training readiness. It seems that we could save lots of money on flying hours over the long term, but we might be unable to prepare adequately for combat.[10]

[10] Also, the cost of training additional pilots to make up for higher attrition, or the cost of bonuses to avoid higher attrition, could more than offset the savings on fuel.

III. ANALYSIS OF MARINE CORPS BOMBING

A. DATA

Alone among the services, the Marine Corps maintains a database at the headquarters level that includes both the performance information and the information on training history needed to examine the existence of statistical relationships between flying hours and aircrew performance. This information is part of the Naval Flight Record Subsystem (NAVFLIRS). After every flight pilots fill out forms describing their flight activity. When this activity includes bombing practice on instrumented ranges, the accuracy with which bombs were dropped is included in the report. NAVFLIRS also includes information on the career flying history of pilots.[11]

Data were obtained on 23,000 flights between January and July 1987. The flights include 649 bombing flights for which information on bombing accuracy was recorded. The database is derived from bombing runs of three kinds of aircraft, the AV-8B, F/A-18, and F4-S. Both manual bomb deliveries and deliveries in which automated fire control systems were employed are included, and every bombing flight is identified as either involving manual or automated bombing. Flights are also identified according to where they fit into the training syllabus that pilots must complete to remain qualified. It was possible to differentiate between basic syllabus flights and advanced syllabus flights. Table 2 summarizes the Marine Corps data.

The range of career experience is slightly larger than it was in the carrier landing analysis. There is somewhat less recent flying. Almost two-thirds of the bombing deliveries were automated. This reflects the fact that the vast majority of AV-8B and F/A-18 deliveries were automated. The F-4S does not have an automated delivery system.

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[11] The Navy also uses NAVFLIRS, but when practice bombing is performed, Navy pilots are not required to report bombing accuracy results to the database. Marine pilots are. NAVFLIRS has only been in use since January 1987. Before that time a similar system called the Flight Readiness Data System (FREDS) kept track of flying-hour histories, but not of bombing accuracy.

Table 2. Description of Data Used In Analysis of Marine Corps Bombing Accuracy

Variable	Minimum	Mean	Maximum
Miss Distance (feet)	0	83	627
Career Flying Hours	226	1,598	5,875
Flying Hours in the Last 7 Days	0	4	22
Automated Delivery[a]	0	0.64	1
In Advanced Part of Syllabus	0	0.24	1
AV-8B Flight	0	0.53	1
F/A-18 Flight	0	0.17	1
F-4S Flight		0.30	1

[a] The last five variables in the table are dichotomous. They either take the value one, showing that an observation has the indicated property, or the value zero, showing that it doesn't. The mean is the fraction of the observations that have the indicated property.

B. ANALYSIS

The central hypotheses of this analysis are that pilots with more career experience drop their bombs more accurately and that greater recent flying experience is associated with more accurate bombing.[12] Important subsidiary hypotheses are that automated bomb deliveries are more accurate than manual ones and that experience—both short-term and long-term—plays a smaller role in determining the accuracy of automated deliveries than of manual deliveries.

Automated delivery systems are meant to increase accuracy and to make bombing easier. It is also expected that bombing accuracy will differ according to the type of aircraft. The newest aircraft, the F/A-18, is expected to be the most accurate and the oldest,

[12] The effect of recent experience on performance may be thought of as working through the training syllabus. The syllabus is put together so that skill is enhanced as a pilot progresses through it. Thus, one might expect greater bombing accuracy on advanced syllabus flights. As the number of recent flying hours rises, pilots become more likely to be in the advanced part of the syllabus. Thus, the flying-hour program can be expected to affect the degree of syllabus completion, which in turn affects performance. This may be termed the *recursive* form of the short-term experience hypothesis. An analysis of this form of the hypothesis was performed and is referred to in a subsequent footnote.

the F-4S, the least accurate. These hypotheses led to the formulation of the following equation:

$$M = b_0 + b_1 \times H_c + b_2 \times H_7 + b_3 \times A + b_4 \times H_c \times A + b_5 \times H_7 \times A + b_6 \times AV8 + b_7 \times F4 \ , \quad (2)$$

where

M = bombing accuracy as measured by the distance by which the bomb misses its target, in feet

H_c = career flying hours

H_7 = flying hours in the previous seven days[13]

A = a dummy variable taking the value 1 for an automated delivery and zero for a manual delivery

AV8 = a dummy variable taking the value 1 for an AV-8B flight and zero otherwise

F4 = a dummy variable taking the value 1 for an F-4S flight and zero otherwise.

$b_0, b_1, b_2, b_3, b_4, b_5, b_6, b_7$ = coefficients to be estimated.

The coefficient b_1 measures the effect of additional career flying hours on bombing performance, and is expected to be negative — better performance is reflected in smaller miss distances. Similarly, b_2, the strength of the short-term influence of flying hours on performance, should be negative. We also expect b_3 to be negative, picking up the role of automated bombing systems in improving accuracy, and b_6 should be positive because the AV-8B is expected to be less accurate than the F/A-18 (the only model of plane that is not explicitly identified by a variable in the equation). We expect b_7 to be positive, because the F-4S is expected to be less accurate than the F/A-18.

The interpretation of b_4 and b_5 is somewhat more complicated. These coefficients measure the degree to which flying hours improve performance differently for automated bombing than for manual bombing. The effect of additional flying is hypothesized to be less for automated bombing. That is to say there should be a less negative impact on miss

---

[13] In the landing grade analysis the short-term experience variable was flying hours in the previous month. The seven-day variable was far more successful in equation (2) than the previous month variable. There is no intrinsic reason why recently honed skills ought to depreciate at the same rate for landing and bombing. It is, however, interesting that the bombing analysis was far more sensitive to the choice of a short-term experience variable than the landing grade analysis was.

distance. In this case b_4 and b_5 will be positive. The effect of additional career flying hours on bombing accuracy for automated runs is measured by $b_1 + b_4$. The effect of additional recent flying hours on bombing accuracy for automated runs is measured by $b_2 + b_5$.

C. RESULTS

The results presented in Table 3 are consistent with all of the hypotheses discussed above.[14] They are presented graphically in Figures 5 and 6. Figure 5 depicts the effect of changing career flying hours, and Figure 6 depicts the effect of changing flying hours in the last seven days. Each graph includes five curves, representing both automated and manual bombing on the three kinds of aircraft (the F-4S only performs manual bombing). The coefficients of both the long-run and short-run flying hour variables are statistically significant in the expected direction. This indicates that, for manual bombing, additional flying hours improve performance. For automated deliveries this is not the case.[15, 16] When the coefficients that reflect the difference in the impact of flying hours between manual and automated flights are added in, additional flying hours affect bombing accuracy very little. As expected, automated deliveries are more accurate than manual deliveries and both AV-8B and F-4S deliveries are less accurate than F/A-18 deliveries.[17]

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14 The analysis that examined the recursive form of the short-term experience hypothesis also yielded positive results. Bombing during the advanced portion of the syllabus was significantly more accurate and pilots who had flown more in the last seven days were significantly more likely to be in the advanced portion of the syllabus.

15 This does not mean that flying hours don't affect pilot proficiency in these aircraft. The mission involves more than delivering bombs accurately. A pilot must be able to survive ground-to-air and air-to-air combat to be able to deliver his bombs. Performance in these extremely challenging aspects of the mission seems likely to benefit from additional flying hours. Research into the relationship between flying hour histories and performance in all aspects of the mission should be pursued. Air-to-air combat is treated in Section IV.

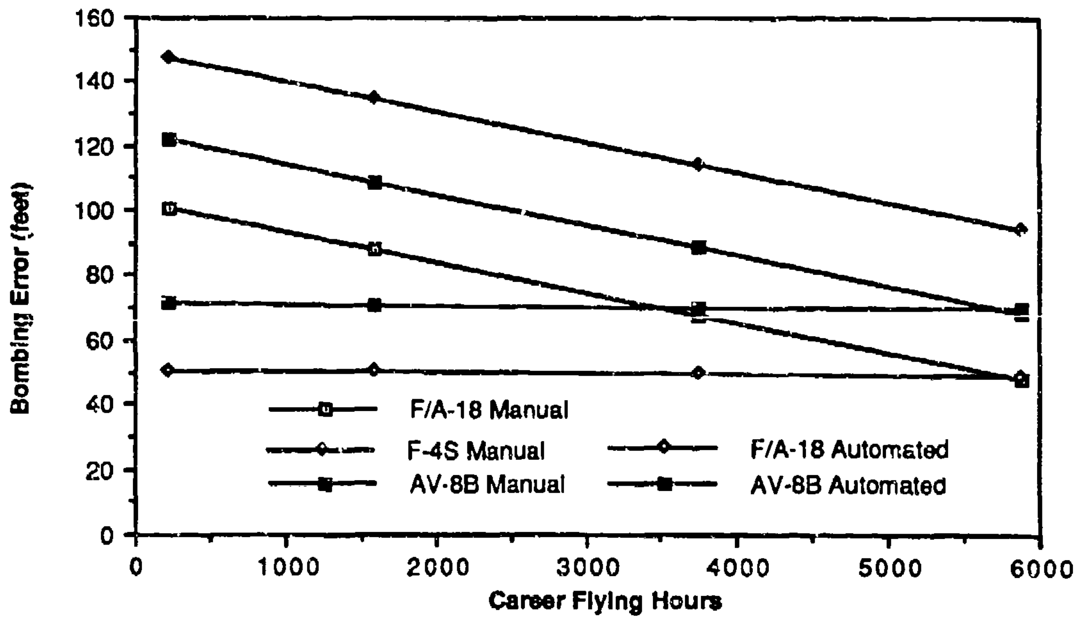
16 The results reported here are quite sensitive to the specification of the functional form hypothesized in Equation (2). Alternative functional forms, which conform slightly better to the data, do not yield statistically significant results. Although we emphasize the intuitively appealing results in Table 3, we are assembling a larger database to validate them.

17 The estimated equation only explains about one-fifth of the variation in bombing accuracy. This means that the equation cannot very precisely predict where an individual bomb will fall based on the explanatory variables in Equation (2). The goal of this paper is not, however, to predict the location of individual bomb deliveries. Rather it is to estimate the effect of flying hours on the average accuracy of a large number of deliveries. The statistical significance of the coefficients relating to the impact of flying hours indicates that it is adequate to this task.

Table 3. Determinants of Bombing Accuracy for Marine Corps Aircraft (Miss Distance in Feet)

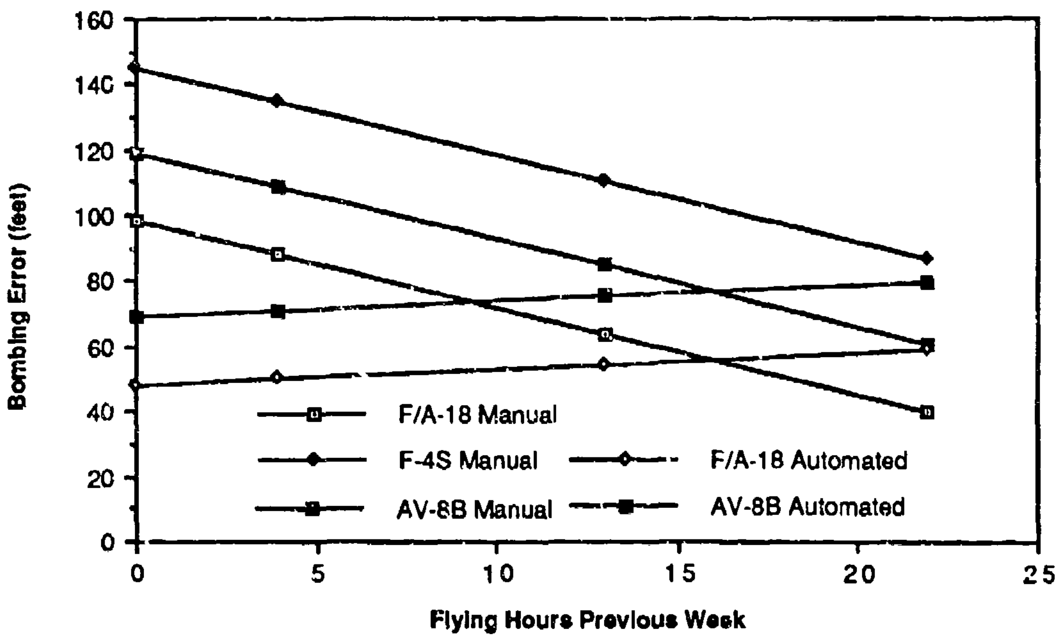
Independent Variable	Coefficient	t-value
Constant	113.4	10.10***
Career Flying Hours (H_c)	-0.0094	2.31**
Flying Hours in the Last Seven Days (H_7)	-2.65	2.07**
Automated Delivery (A)	-64.61	5.62***
H_c x A	0.0091	1.80*
H_7 x A	3.13	1.87*
AV-8B Flight	20.96	3.05***
F-4S Flight	46.78	4.57***

Note: Adjusted R^2 = .18.
* Significant at the .90 level.
** Significant at the .95 level.
*** Significant at the .99 level.



Note: Flying hours during previous week at mean.

Figure 5. Bombing Error Versus Career Flying Hours



Note: Career flying hours at mean.

Figure 6. Bombing Error Versus Flying Hours During Previous Week

According to the estimates of the coefficients of Equation (2), if flying hours were reduced 10% for a short period of time, the average miss distance in bombing runs would rise by about 1% for manual bomb deliveries. If the reduction continued indefinitely, an additional increase of more than 1% would be incurred. Once again, most of the impact of a change in flying hours on performance appears to operate through its effect on total pilot experience. A pilot with 3,000 career hours of experience on average can be expected to place bombs 24 feet closer to the target than a pilot with 500 hours.

These results are largely consistent with those obtained in a 1986 Air Force study [5]. That study examined the relationships between flying experience and bombing accuracy in the A-10 and F-16 aircraft. It found both long-term and short-term experience effects with the long-term effects more pronounced than the short-term effects.

IV. ANALYSIS OF AIR-TO-AIR COMBAT EXERCISES

Approximately every eighteen months, each Navy F-14 squadron in the Atlantic Fleet participates in training for air-to-air combat at Oceana Naval Air Station. The training—called the Fleet Fighter Air Combat Readiness Program (FFARP)—consists of flying a series of exercise missions against highly trained pilots who simulate Soviet tactics. Each exercise consists of a control phase and a weapons phase. During the control phase the aircraft crews attempt to gain and maintain radar lock-on and position themselves for an attack. The control phase ends when the enemy aircraft is sighted and visually identified. The weapons phase begins when a weapon is fired and continues until all Blue or all Red aircraft have been "killed." Particularly in the early exercises, Red aircraft may be reactivated in order to give the Blue crews more experience. Reactivated aircraft return to the exercise area perimeter before rejoining the exercise.

The exercises are conducted with the aid of a Tactical Air Combat Training System (TACTS). This system continuously monitors signals from all the aircraft participating in an exercise. It tracks their positions, observes when a plane "fires" a weapon, and simulates the performance of the weapon. Every firing is scored by the system according to various parameters, such as speed, attitude, range, acceleration, and altitude of the firing and target aircraft.

The F-14 is a two-seat aircraft. The pilot flies the plane and the radar intercept officer (RIO) is responsible for keeping track of and targeting threatening aircraft. Either crew member can fire missiles.

Missions are flown by groups of two or more "Blue" F-14s against a number of aggressor or "Red" aircraft. Successive exercises become more complex as engagements progress from two against two to four against many Red aircraft. Information is kept on every missile shot and gun firing. In addition to who shot and whether the shot hit its target, there are data on the range at which radar contact was made and the target locked on to. The ranges at which the target was observed, visually or on television, and identified are recorded, as is information on firing range, altitude, elapsed exercise time when a weapon is fired, and the missile type in use (for missile shots).

A. DATA

Our analysis was based on 585 sorties involving 1,820 missile and gun shots. Of these 1,820 attacks, 1,352 were classified as valid firings. Each valid firing is an observation. Attacks by aircraft that were already "dead" or against "dead" opponents were eliminated from the data base. A total of 967 valid Blue shots were recorded, 562 of which were successful. Valid Red shots numbered 384 with 131 successes.

Average pilot experience was 1,776 hours, ranging from 387 to 4,186. RIOs had less experience, averaging 1,332 hours with a range of 226 to 3,772. Pilots' flying hours in the previous month were between 11 and 38, with an average of 21. RIOs averaged 18 hours in the previous month, with a range of 4 to 38.

The definitions of variables used in the analysis are:

- Performance Variables
  - Red shoots and kills (Y_0)
  - Red shoots and misses (Y_1)
  - Blue shoots and misses (Y_2)
  - Blue shoots and kills (Y_3)
- Targeting Effectiveness Variables
  - Lock Range Delta (R_1): The difference between the range at which the crew begins the exercise and the range at which radar lock-on is made.
  - Tally-Ho Range (R_t): Range at which Red aircraft is sighted, either visually or on TV.
- Crew Experience Variables
  - Pilot's total career flight hours (H_{pc})
  - Radar Intercept Officer's career flight hours (H_{rc})
  - Pilot's flight hours in the month prior to the beginning of the FFARP (H_{p30})
  - Radar Intercept Officer's flight hours in the month prior to the beginning of the FFARP (H_{r30})
- State Variables
  - Red Odds (O_r): The ratio of Red to Blue aircraft when the shot is fired.
  - Advanced exercise (E_{adv}): Equals one for Competitive exercise or more than two Blue aircraft, and zero otherwise.

- Red supersonic (S_r): Equals one if opposing Red aircraft is supersonic, and zero otherwise.[18]

Performance variables are the set of mutually exclusive and exhaustive outcomes of each firing. We hypothesize that performance is significantly related to crew experience. Targeting effectiveness variables are meant to capture the proficiency of the crew in locating enemy aircraft and in positioning their own aircraft for an attack. They should also be affected by crew experience. State variables reflect factors over which Blue has little or no control and which are not related to experience.

B. ANALYSIS

Our central hypothesis is that the probability of a given outcome depends on both the recent and career flight experience of the pilot and RIO, and on the exercise environment. The exercise environment is described by the state variables.

Our formulation assumes that performance is determined directly by targeting effectiveness. Targeting effectiveness—represented by R_l and R_t—is, in turn, influenced by both the recent and career experience of the pilot and RIO. Career experience of the pilot—who attempts to place the aircraft in the most advantageous position and attitude to assure success—also enters directly as a determinant of performance. The other crew experience variables were tried, but did not prove important in this role.

The model is defined by Equations (3) through (5).

$$\ln (p_i/p_0) = a_{i0} + a_{i1} \times H_{pc} + a_{i2} \times R_l + a_{i3} \times R_t + a_{i4} \times O_r + a_{i5} \times E_{adv} + a_{i6} \times S_r\,, \quad i = 1, 2, 3 \tag{3}$$

$$R_l = b_0 + b_1 \times H_{pc} + b_2 \times H_{rc} + b_3 \times H_{p30} + b_4 \times H_{r30}, \tag{4}$$

$$R_t = c_0 + c_1 \times H_{pc} + c_2 \times H_{rc} + c_3 \times H_{p30} + c_4 \times H_{r30}, \tag{5}$$

where

p_i = the probability of achieving the i^{th} outcome (Y_i)

a_{ik}, b_i, c_i = coefficients to be estimated

and the right-hand variables are as previously defined.

Equation (3) defines the multinomial logit (conditional logit) model, which is described in detail by Maddala [6, p. 41] and T. Amemiya [7, p. 1516]. Maximum

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[18] The Red supersonic dummy was included in the analysis as a control. The coefficients of this variable are not reported because of the potential sensitivity of the variable.

likelihood estimates of Equation (3) were made using the Newton method [8, p. 150]. The coefficients of Equations (4) and (5) were estimated using ordinary least squares. The partial derivatives of the p_i, i = 0, 1, 2, 3 with respect to the right-hand variables in Equation (3) were calculated using a FORTRAN program written by Matthew Goldberg of IDA. The derivatives of the p_i with respect to the individual experience variables were then computed using the p_i partial derivatives from Equation (3) and the estimated coefficients of Equations (4) and (5).

We expect the coefficients of Equation (4) to be negative. More experienced crews are expected to lock on to the target sooner. Tally-ho range, analyzed in Equation (5), is expected to depend positively on all of the experience variables. The ability to spot aerial targets is learned behavior.

Table 4 summarizes our hypotheses concerning the partial derivatives of the probabilities of a Red or Blue kill with respect to the experience and state variables. We cannot hypothesize the effect on Red or Blue misses. The model is unordered in that it is not clear that a Red miss is better or worse than a Blue miss. One might speculate that it is always better to shoot and miss than to be shot at. However, a missed shot may give away the shooter's position or allow the opponent time to gain a favorable position.

Table 4. Hypothesized Signs of the Partial Derivatives of the Probability of a Red or Blue Kill with Respect to the Experience and State Variables

	Dependent Variable	
Independent Variable	P (Red Kills Blue)	P (Blue Kills Red)
Pilot Career Hours (H_{pc})	–	+
RIO Career Hours (H_{rc})	–	+
Pilot Hours Previous Month (H_{p30})	–	+
RIO Hours Previous Month (H_{r30})	–	+
Red Odds (O_r)	+	–
Advanced Exercise (E_{adv})	+	–

C. RESULTS

Table 5 shows the results, in partial derivative form, of estimating the coefficients of Equation (3). The model was estimated with each observation being an individual shot. The signs of all of the partial effects are consistent with the hypotheses outlined above.

The targeting effectiveness variables are significantly related to the probability of a Red hit and of a Blue hit and both hav the expected sign.

Table 5. Determinants of Performance in Air-to-Air Combat

Independent Variable	Outcome: Red Hits Blue	Red Miss	Blue Miss	Blue Hits Red
Pilot Career Flight Hours	-2.56E – 05 (5.02)***	-7.72E – 06 (0.773)	-2.93E – 06 (0.247)	3.63E – 05 (2.87)***
Radar Lock Delta	2.03E – 03 (2.94)***	4.47E – 03 (3.14)***	1.40E – 03 (0.806)	-5.09E – 03 (2.70)***
Tally-ho Range	-4.15E – 03 (2.80)***	-1.42E – 02 (4.36)***	-2.15E – 04 (.058)	1.85E – 02 (4.61)***
Red Odds	1.74E – 02 (4.36)***	2.05E – 02 (2.10)**	-1.37E – 02 (0.97)	-2.42E – 02 (1.59)
Advanced Exercise	4.64E – 02 (3.96)***	-6.91E – 03 (0.29)	3.72E – 02 (1.27)	-7.66E – 02 (2.45)**
Number of Observations		1,352		

Note: Numbers in parentheses are t-values.
** Significant at the .95 level.
*** Significant at the .99 level.

The signs of the state variable partial effects are consistent with the hypotheses stated in Table 4. All of the state variable coefficients are significant at the .95 level, except for the effect of Red odds at the time of the shot on the probability of a Blue hit.

Table 6 shows the partial effects of crew experience on the targeting effectiveness variables. These results are consistent with our hypotheses except for three instances. The long-term experience variables are not significantly related to the distance covered between the start of the exercise and radar lock-on. We cannot explain why long-term experience is not related to this dependent variable, particularly in the case of the RIO. The fact that the RIO short-term experience variable is not significantly related to tally-ho range is more understandable. The pilot has a greater role in visually sighting the target, just as the RIO has primary responsibility for the radar part of the control phase.

Table 6. Determinants of Targeting Effectiveness

Independent Variable	Lock Range Delta	Tally-ho Range
Constant	2.74E + 01 (28.4)***	-1.26E + 00 (2.40)***
Pilot Career Flying Hours		5.57E – 04 (6.34)***
RIO Career Flying Hours		9.56E – 04 (9.71)***
Pilot Flight Hours Previous Month	-9.91E – 02 (2.82)***	1.58E – 01 (9.59)***
RIO Flight Hours Previous Month	-1.64E – 01 (4.39)***	2.06E – 02 (1.15)
Number of Observations	1,352	1,352
R-Square	0.02	0.13

Note: Numbers in parentheses are t-values.

*** Significant at the .99 level (two-tailed test).

The determinants of performance related to our principal hypothesis are shown in Table 7. All of the signs are consistent with our hypothesis, and the effects are highly significant. The implications of these results can be more clearly seen by calculating the arc elasticities of performance with respect to each of the experience variables. The arc elasticities were calculated to show the expected percentage change in performance associated with a 10% change, from the mean, of experience.

If we assume a 10% decrease in all of the experience variables the total effect on performance would be a 4.8% decrease in the probability of a Blue kill and a 9.2% increase in the probability that Red kills Blue. Eighty-five percent of the expected change in Red kills is attributable to the effect of changes in pilot flying hours (both career and recent flying), as is 80% of the expected change in Blue kills. The remaining change is accounted for by decreases in RIO career and short-term flight hours in approximately equal amounts. Pilot career flight time is the most important factor, accounting for 65% of the increase in Red kills and 42% of the decrease in Blue kills.

Table 7. Full Effects of Flying-Hour Variables on Performance in Air-to-Air Combat

Independent Variable	Red Hits Blue	Red Miss	Blue Miss	Blue Hits Red
	Outcome			
Pilot Career Flight Hours	-2.79E – 05 (5.56)***	-1.56E – 05 (1.57)	-3.05E – 06 (0.257)	4.66E – 05 (3.72)***
RIO Career Flight Hours	-3.97E – 06 (2.69)***	-1.35E – 05 (3.98)***	-2.06E – 07 (0.058)	1.77E – 05 (4.17)***
Pilot Flight Hours Previous Month	-8.57E – 04 (3.36)***	-2.68E – 03 (4.48)***	1.05E – 04 (0.171)	3.43E – 03 (4.57)***
RIO Flight Hours Previous Month	-4.18E – 04 (2.69)***	-1.02E – 03 (2.65)***	2.26E – 04 (0.753)	1.22E – 03 (2.44)**
Number of Observations		1,352		

Note: Numbers in parentheses are t-values.
* Significant at the .90 level.
** Significant at the .95 level.
*** Significant at the .99 level.

The effect on the probability of Red and Blue hits of each of the experience variables is shown graphically in Figures 7 and 8. Each experience variable is allowed to vary over its observed range and all other variables are held constant at their observed means. These graphs illustrate the relatively large contribution of an increase in pilot flight hours, especially career flight hours, to a decrease in Red kills and an increase in Blue kills.

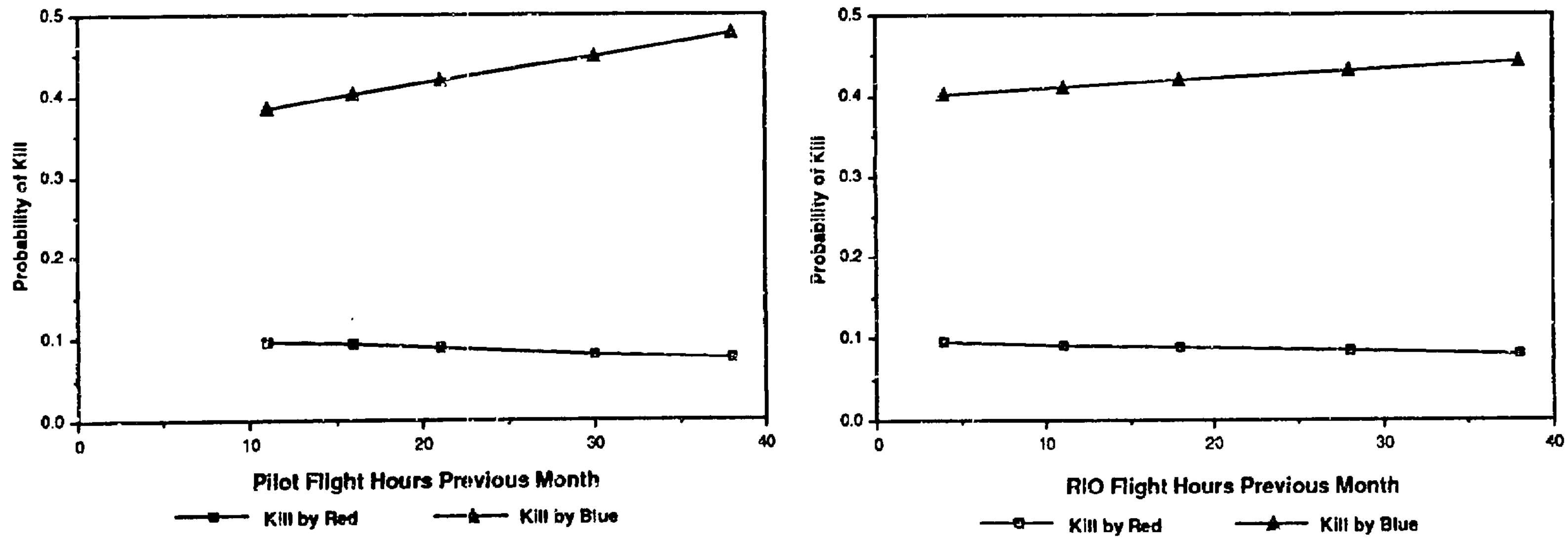

Figure 7. Recent Flying Hours and Performance In Air-to-Air Combat

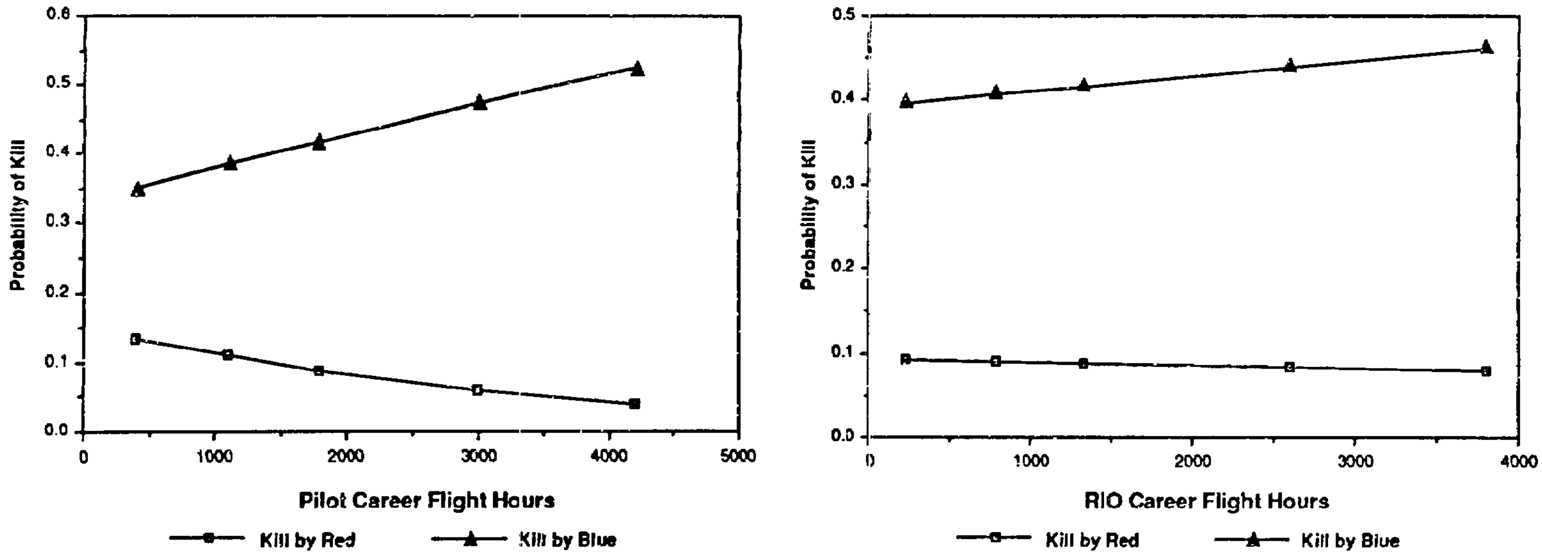

Figure 8. Career Flying Hours and Performance in Air-to-Air Combat

V. SERVICE-SPONSORED RESEARCH ON FLYING HOURS AND PERFORMANCE

The General Accounting Office has criticized both the Air Force and the Navy for failing to relate flying hours to measures of performance [1], [9]. Both services are currently either performing or sponsoring research into the performance implications of variations in flying-hour programs. This chapter provides a brief overview of these efforts.

A. TACTICAL AIR COMMAND (TAC)

The Tactical Air Command has recently completed a quick study of the implications of changes in the flying-hour program for aircrew safety.[19] The analysis examined year-to-year fluctuations in accident rates in TAC as a function of the number of hours flown during a period from the early 70s to the mid 80s. A strong inverse relationship was found between the two variables. Flying hours were high during the early part of the period, then fell in the late 70s and rose in the 80s. Accident rates displayed the opposite fluctuations, rising in the late 70s and falling in the 80s. A quantitative relationship between flying hours and accident rates was derived.

The study used this relationship to perform a cost-benefit analysis. The savings that accrued by reducing flying hours were compared with the additional costs due to losing more aircraft and pilots. The cost of pilots reflected the high cost of their training. The study found the cost savings from flying less were fully offset by the costs of additional accidents.

TAC is conducting a much more detailed study of flying hours and performance. The research developed task-oriented performance indicators for training events associated with all of TAC's tasks.

Proficiency was related to flying-hour histories in a test performed in two squadrons in 1989. Learning curves were developed for both experienced and

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[19] The written results of this analysis are not available at the time of this writing. The information here is based on discussions with TAC personnel.

inexperienced pilots in a variety of tasks. The work may be extended to additional aircraft types.

B. STRATEGIC AIR COMMAND (SAC)

SAC Headquarters initiated a study of the effect of variations in flying-hours on performance in bombing competitions [10]. Several measures of performance were correlated with career and recent flying experience for aircrew members. The results of this work were disappointing.

No consistent relationship between performance and flying hours was found. Many factors could help explain this result. For example, the crews in bombing competitions are selected from among the best crews. Flying hour histories could have little relationship to proficiency within this select group, but still be important for the wider population of aircrew members. Strategic bombing is highly automated. As the Marine Corps analysis showed, the accuracy of automated bombing may be little affected by flying hours. Other, more tactically-oriented parts of the SAC mission may be more affected. Also, bombers are multi-person aircraft. It may be difficult to attribute aspects of performance to the experience of individual crew members, which is what the SAC study tried to do.[20]

SAC is continuing work in this area that draws on the lessons of its first effort. A structured experimental design is being used. Many aspects of performance are being scored by trained observers. Initial results are encouraging. In addition, a research project has been initiated by Systems Research and Applications Corporation (SRA) with support from the Air Force. The SRA work is focusing on the performance of tanker crews.

C. MILITARY AIRLIFT COMMAND (MAC)

The Air Force Human Resources Laboratory (AFHRL) is sponsoring a program of research into the effectiveness of training for the C-130. A principal objective is to evaluate a new program of contractor-managed classroom training, but the AFHRL personnel involved are also supporting efforts to investigate the importance of flying hours for performance in the C-130.

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[20] The landing grade analysis for the Navy E-2C, a two-pilot aircraft, also proved unsuccessful. There may be a pattern here.

D. THE NAVY

The Navy's Aviation Manpower and Training Division has asked the Center for Naval Analyses to begin a study of flying hours and performance. A long-term effort is proceeding. The plan is to follow several squadrons through the training and deployment cycle to develop an in-depth understanding of what performance measures should be capturing and what available measures actually capture. If existing data are felt to be inadequate, recommendations will be made concerning the development of alternative data. After appropriate measures of performance have been decided on and the necessary data gathered, analysis of the impact of flying hours on performance will begin. In addition to initiating this new study effort, the Navy has been actively helping the Institute for Defense Analyses acquire the data needed to perform the work described here.

VI. CONCLUSIONS

- Existing data on performance can be used to develop relationships between aircrew performance and both long-term and short-term experience variables that reflect the impact of variations in the flying-hour program.
- The quality of Navy carrier landings, the accuracy of Marine Corps bombing, and the performance of Navy aircrews in air-to-air combat are influenced by the number of hours pilots have flown, both recently and over the course of their careers.[21]
- A 10% reduction in flying hours is estimated to increase unsatisfactory landings by 10% and decrease excellent landings by 5% over the long term. Such a reduction is also estimated to decrease bombing accuracy by about 2% for manual bomb deliveries. Additional flying hours have not been found to affect the accuracy of automated bomb deliveries. A 10% decrease in flying hours for fighter aircrews is estimated to increase the probability that red kills blue by 9% and reduce the probability that blue kills red by 5%.
- Research to date has focused on only a few aspects of the jobs assigned to aircrew members—bombing accuracy, landing proficiency, and flying safety. Our analysis of air-to-air combat has expanded both the range of tasks and the number of crew members entering the analysis.
- The long-run effects of flying hours on performance appear to be more quantitatively important than the short-run effects. This is illustrated in Table 8. It means that in an emergency it would be difficult to remedy an inadequate level of training. The availability of aircraft and of training ranges would further constrain the ability to improve training readiness quickly.

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[21] There was some concern that the apparent importance of career experience might, to some extent, be a statistical artifact. This could be the case if good pilots are more likely to stay in the service and accumulate a large number of flying hours. To examine this hypothesis the analysis of air-to-air combat was redone with only pilots who were believed to be in the first term of service. The results of this reexamination did not differ much from the results reported in Section IV. The interpretation that more flying causes better performance (rather than the reverse) seems to be correct.

Table 8. Impact of 10-Percent Cuts in Flying-Hour Variables on Performance

Performance Measure	Career Flying	Recent Flying	Total
Unsatisfactory Landings	6.9%	2.6%	9.5%
Bombing Miss Distance	1.5%	1.0%	2.5%
Air-to-Air Combat			
Probability Red Kills Blue	6.3%	2.9%	9.2%
Probability Blue Kills Red	-2.6%	-2.2%	-4.8%

VII. FUTURE RESEARCH

A start has been made in linking flying hours to indicators of aircrew proficiency. Analysis of objective data has shown that, in selected cases, reductions in flying hours will lead to measurable degradations in mission performance. Still, there is much work left to be done.

Research to date has focused on just a few aspects of the jobs assigned to aircrew members—bombing accuracy, landing proficiency, flying safety, and air-to-air combat.[21] Many critical parts of the missions entrusted to military aircrews have not been analyzed. These include in-flight refueling, helicopter operations, and low-level cargo drops. Existing evidence can be used to help justify flying-hour programs, since it shows that flying hours make an objectively measurable difference, but it cannot show that they make a difference everywhere.

In addition to the omission of some missions from the body of successful flying-hour research, the role of flying hours in enhancing the level of performance in large aircraft (e.g., tankers, bombers, and cargo aircraft) has not been demonstrated quantitatively. The task of attributing aspects of performance to the experience of individual aircrew members is obviously harder in a crew made up of many people.

IDA plans to focus its continuing research program on the gaps in the flying hour literature. The training research being done by MAC is expected to result in the development of performance and flying-hour data for the C-130. IDA is maintaining contact with the MAC researchers and has assembled a performance and flight hour data base for an analysis of C-130 drop accuracy. An effort will be made to gather data for an analysis of helicopter performance for at least one of the services.

Over the next few years it is realistic to hope that illustrative relationships between flying hours and performance will be developed that cover most important aircrew missions and most types of aircraft. These relationships should provide a broad-based justification of the importance of flying hours in producing and maintaining aircrew readiness. One

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[21] In addition to the recent work at TAC, the Naval Safety Center has performed research that showed a link between career flying hours and accident rates [11].

must be careful, however, not to expect too much from these relationships. There are two valuable products they are not likely to provide.

The kinds of relationships developed in this paper are not, by themselves, adequate for the task of determining how many flying hours are enough. There are two reasons for this. First, the estimates of the quantitative relationships between flying hours and performance that they provide are not very precise. They are adequate for giving us confidence that a positive relationship exists between flying hours and performance, and they provide a plausible estimate of the magnitude of the relationship, but the actual magnitude of the relationship is still quite uncertain. Second, there is usually no indication of what level of performance is necessary. Is it adequate for 87% of carrier landings to receive grades of 3.0 or above, or is 90% an appropriate goal? What difference does it make for the operation of a carrier battle group in either peacetime or war? Without answers to questions like these, even precise relationships between flying hours and performance cannot tell us how many flying hours should be budgeted for.

In addition, information on relationships between aggregate flying hours (either long-term or short-term) and performance provide little guidance about the appropriate design of aircrew training programs. They cannot tell us how to change the frequency with which particular tasks are practiced in order to minimize the number of flying hours needed to develop overall mission proficiency. This kind of insight depends on doing analysis at the task level. The TAC, MAC, and CNA research efforts all have the development of such insight as one of their goals. Successfully performing research of this type for even one kind of aircraft requires much more attention to data development than does research oriented to demonstrating the overall value of additional flying hours. It very much deserves to be pursued, but quick, wide-ranging payoffs should not be expected.

Research on flying hours and performance should follow a two-pronged path. Work to show, in rough terms, how much additional flying hours enhance performance for a wide range of aircraft and missions should yield useful results relatively quickly—if adequate resources are applied to the area. At the same time, analysis of task-oriented performance data could yield new insights into the proper design of aircrew training programs over a longer period.

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